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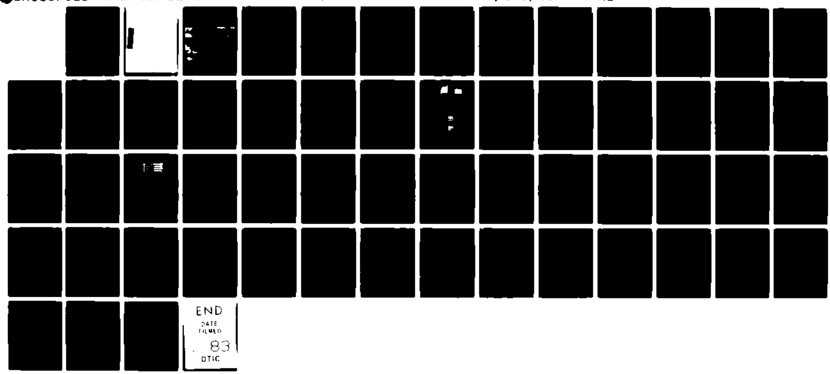

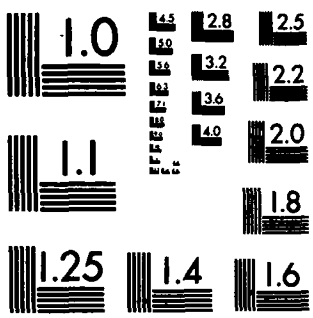

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TABLE II. Comparisons Between Morning Shift and Evening Shift

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16. Abstract

Ten years of research on physiological stress in air traffic control specialists (ATCS's) is reviewed. Data were derived from 20 tasks involving the experimental variables of workload, shift-rotation patterns, and automation. Field studies were carried out at Air Traffic Control Towers at Chicago O'Hare International Airport, Houston Intercontinental (two studies), Opa Locka (Florida), Roswell (New Mexico), and Fayetteville (Arkansas); at Air Route Traffic Control Centers at Miami, Atlanta, and Fort Worth; and at Flight Service Stations at Oklahoma City, Roswell, and Fayetteville. Laboratory studies at the Civil Aeromedical Institute consisted of a survey of the quantity and quality of sleep in working ATCS's, a restudy of ATCS's several years after the first study to appraise stress change, and experimental attempts to evoke a differential response to two different qualities of stress. Stress was distinctly related to imposed workload as well as to working conditions. Differences in stress levels in ATCS's on different shift-rotation patterns were minimal. Automation gave rise to increased total stress accounted for by an increased workload incident to the changeover period from manual to computerized control techniques. A stress index was developed to facilitate comparison of physiological stress at the different air traffic control (ATC) facilities and among ATCS's. Anxiety level measurements vary minimally from facility to facility indicating little impact of ATC work on the psychological state of ATCS's. These and other measures show that it is clearly inappropriate to describe ATC work, as is commonly done in the popular press, as being unusually stressful.

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PHYSIOLOGICAL STRESS IN AIR TRAFFIC CONTROLLERS: A REVIEW

INTRODUCTION

The air traffic control (ATC) system that evolved in the period immediately after World War II relied on position reports radioed by pilots to air traffic control specialists (ATCS's). Because of uncertainties inherent in such a system, aircraft separations in trail were large (60 to 120 miles) by today's standards and system capacity was correspondingly small. In order to increase production and to meet schedules, it was a common practice for airline pilots to fly "off airways" in uncontrolled airspace. As a result, it was predicted that a catastrophic midair collision would occur, probably over a large city where traffic was concentrated. Such a collision did occur, but in one of the nation's most remote locations instead of a metropolitan area. On June 30, 1956, a United Air Lines DC-7 and a Trans World Air Lines Constellation collided over the Grand Canyon, killing all 128 persons on board both aircraft. The two airliners were eastbound out of Los Angeles flying in uncontrolled airspace under visual flight rules at the time of the accident. The tragic occurrence was a watershed event and served to heighten the government's apprehension about inadequacies of ATC; it also caused acceleration of plans for modernization of the airspace system. As Komons defined the situation in the fifties regarding air traffic control and airway development, " . . . public policy had failed to keep pace with the relentless march of a runaway aviation technology" (20).

The Grand Canyon crash also aroused unprecedented public concern about the "crowded sky." Books and articles fed public fears about air safety in general and midair collisions in particular (7). The press hotly attacked the (then) Civil Aeronautics Authority and Congress. ATC felt the reflected heat.

With the advent of jet airliners in the late fifties, questions became increasingly urgent about the adequacy of the ATC system to provide safe separation of aircraft flying at higher altitudes and at ever-greater speeds. Controllers, feeling intense pressure, complained of task overload and excessive responsibility; the word "stress" began to be associated more and more with ATC.

Nowhere were these complaints more strident than at O'Hare International Airport in Chicago, Illinois. O'Hare is unique among airports in its rapid rise to prominence. In less than 20 years the site of this airport changed from farmland into the world's busiest air terminal. In 1942 the government acquired land west of Chicago where it built a wartime runway and aircraft assembly plant operated by Douglas Aircraft Company, facilities that were declared surplus in 1946. The city of Chicago promptly bought the site plus some adjacent land for a major new airport to replace Chicago Municipal Airport (Midway), the city's only air carrier airport and, then, the busiest in the world. However, Midway's runways could not be lengthened to accommodate heavy jets and soon became obsolete; O'Hare then became Chicago's primary airport. Originally, the airport was known as Orchard Place Airport; a reminder of its beginnings survives in its three-letter identifier, ORD (2). By 1961 O'Hare supplanted Midway as the busiest airport in the world.

O'Hare was a new airport as far as terminal facilities were concerned, but the air traffic control tower (ATCT) and the equipment in it were obsolete. Equipment failures were frequent and the view of taxiways from the tower cab was inadequate.

Problems related to inadequate staffing, obsolete equipment, heavy workload, and associated stress continued to grow at O'Hare. In 1968, the Civil Aeromedical Institute (CAMI) was requested by the Air Traffic Service through the Federal Air Surgeon to carry out studies at O'Hare ATCT to identify and quantitate sources of physiological stress. The research task was assigned to the Stress Physiology Research Unit of the Aviation Physiology Laboratory in CAMI's Aeromedical Research Branch. Twenty-one subsequent field studies at other facilities and two laboratory studies were carried out over the next 10 years in an effort to characterize and provide a general concept of stress in ATCS's (Table I). This review is a summary of those studies, most of which have been previously published.

METHODS

Stress was appraised by a battery of tests, the composition of which changed somewhat over the course of the studies as redundant, unrewarding, and impractical tests were dropped. Generally, the test battery consisted of physiological and biochemical measurements. In the study at O'Hare (9), physiological measurements taken were ambulatory electrocardiogram (ECG), galvanic skin response (GSR), blood pressure, and body temperature. Biochemical measurements were made of fibrinogen and phospholipids in blood and, in collaboration with the USAF School of Aerospace Medicine at Brooks Air Force Base, Texas, of urinary 17-OH corticosteroids (17-OHCS), epinephrine (e), norepinephrine (ne), sodium, phosphorus, potassium, urea, and creatinine (cr). In later studies urine analyses were done at CAMI. Urinary sodium, phosphorus, potassium, and urea were dropped from the battery of tests and measurement of 17-OHCS was changed to measurement of 17-ketogenic steroids (st), the precursors of 17-OHCS. All blood measurements were dropped because venipuncture had an adverse effect on ATCS participation and because analysis for serum phospholipids, originally done collaboratively at the Naval Air Development Center, Johnsville, Warminster, Pennsylvania, could not be done at CAMI or done reliably on contract within budgetary constraints. Measurements of metallic ions and urea were dropped because they were judged not to contribute significantly to estimates of stress. The GSR was dropped because its measurement interfered with ATCS's activities.

Subjects were all volunteers an the results of these studies are subject to the bias so created. However, there was no obvious difference in attitudes or condition of volunteers in one facility from subjects in any other facility. Some ATCS's did not volunteer because their scheduled shifts did not meet experimental design criteria. Others had conflicts with scheduled annual leave or training; still others were on medication (e.g., steroids, vitamins, antibiotics) that would have interfered with the biochemical tests on urine. Only a few ATCS's refused to participate on principle.

Subjects reported 30 min prior to regular worktime for preshift testing and ECG electrode hookup. Overtime pay was provided as an incentive for participation. Each subject was instructed to void and discard urine on retiring the night before testing and to collect all urine voided from then through arising time, thus collecting all urine formed during the sleep period. They were similarly instructed to void

TABLE I. Studies Related to Stress in ATCS's

Facility (Identifier)	Date of Study	Main Variable	Reference
O'Hare ATCT (ORD)	1968	Workload	4,9
Houston Intercontinental ATCT (IAH)	1970	Workload	10
Houston Intercontinental ATCT (IAH)	1971	Shift Schedule	11
Opa Locka ATCT (OPF)	1972	Type of Work-Workload	12
Miami ARTCC (MIA)	1972	Type of Work-Workload	12
Bay Area Approach Control ATCT (OAK)	1972	Preautomation	14
Los Angeles Approach Control ATCT (LAX)	1972	Preautomation	14
Atlanta ARTCC (ATL)	1973	Shift Schedule	13
Fort Worth ARTCC (FTW)	1973	Shift Schedule	13
Oakland TRACON (OAK)	1974	Postautomation (ARTS III)	14
Los Angeles TRACON (LAX)	1974	Postautomation (ARTS III)	14
The Relationship Between Stress-Related Metabolites and Disqualifying Pathology in Air Traffic Control Personnel	1975	Stress and Medical Conditions	16
Oklahoma City FSS (OKC)	1976	Type of Work-Workload	15
Fayetteville FSS (FYV)	1976	Type of Work-Workload	15
Fayetteville ATCT (FYV)	1976	Workload	15
Roswell FSS (ROW)	1977	Type of Work-Workload	15
Roswell ATCT (ROW)	1977	Workload	15
Sleep in Air Traffic Controllers	1977	Survey of Sleep Related to Shift Work	22
Stress in Air Traffic Controllers: A Restudy of 32 Controllers 5 to 9 Years Later	1978	Stress Progression	18
Experimental Attempts to Evoke a Differential Response to Different Stressors	1978	Stressor-Specific Responses	17

and discard urine just before entering on duty and then to collect in one vessel (or more if necessary) all urine formed during the work period. Normally, subjects collected the last specimen just before they went off duty. Urine that represented the rest and work periods was thus collected daily. Collections were made into quart plastic bottles containing an excess of dry boric acid as a preservative. Specimens were frozen on receipt from the ATCS's and kept frozen until thawed for analysis at CAMI. Values for urinary hormones were expressed as the creatinine-based ratio (w/w) because of uncertainties regarding collection times and volumes (10).

The ECG was recorded on 0.25-in magnetic tape by battery-operated electrocardiographs carried in shoulder-slung pouches. The recorder speed was 0.125 in/s and recorders would operate reliably for 12 h on one battery. ECG tapes were played back at a speed of 7.5 in/s, thus giving a 60:1 time advantage when the taped data were reduced. The tape playback system was coupled to a digital counter and printer set to count for 1 s and print the count on paper; 1 s of playback was equal to 1 min of recording time. With this system, ECG's recorded continuously throughout an 8-h shift could be reduced in 8 min to a list of 1-min heart rates (HR's).

A total of 402 ATCS's served as subjects in these studies.

Of the variables studied, workload was undoubtedly the most important. Excessive workload was the primary stressor identified by ATCS's. Difficulty arises, however, in attempting to define "workload." If it is defined as the sum of all activities engaged in by an ATCS that occur at the workplace during duty hours, then factors other than ATC per se, such as training, crew conferences, etc., enter into consideration. Traffic count is a good measure of total facility workload, but is not evenly distributed as to quantity or quality among all controllers. Traffic count is useful for comparing total workload at different facilities or for comparing the workload of a given position (e.g., local control) at different facilities and was so used in these studies.

Radio time (RT) is defined as the accumulated time that an ATCS spends in radio contact with pilots. The reasoning behind the selection of RT as a measure of workload is that ATC is being carried out only when information relevant to a flight is being received or transmitted. This definition is a narrow one and does not take into consideration the time a radar controller spends watching traffic without verbally communicating with pilots. Furthermore, a radar controller may have traffic on his cathode ray tube (CRT) or "scope" with which he is not in communication but which, nonetheless, influences his control decisions and thus affects his workload. In spite of these qualifications, RT was the best single measure of workload available to us in these studies. RT was obtained by connecting a seven-channel tape recorder to the output of the facility's recorder amplifier, thus recording both incoming and outgoing radio transmissions for each work position. The tapes were played back with the reproducer outputs connected to voice-actuated relays which, in turn, controlled digital time accumulators. As ATCS's switched work positions or radio frequencies, tape recorder inputs were changed to follow from one position to another. Total RT for each controller on each shift was thus obtained.

A battery of measurements was chosen to describe stress because of some degree of stressor-response specificity. The adrenal cortical response reveals primarily chronic stressors such as labor-management conflicts, marital problems, financial difficulties, etc. The adrenal medulla is primarily responsive to acute workload or stimuli that are exciting or arousing. Ne from sympathetic nerve endings is liberated mainly in response to physical exertion. HR is an indicator of momentary events.

The volume of data from these studies made it difficult to generalize about the findings in a concise and comprehensible way. It was recognized that an index was needed that would integrate some of the measures and thus facilitate various comparisons (12).

Development of such an index was complicated by several factors. First, the stress indicator hormones (SIH) in urine do not occur in equal amounts. There is about a thousand times as much steroid material as there is of catecholamines. If the assumption is made that the three SIH's are equal in importance, then raw data must be treated mathematically so that their relative importance is expressed. After several studies had been carried out, there w so many values for each SIH that the mean of each SIH was stable. Each value divided by this mean, termed the grand mean ($\overline{x}_G$), was thus weighted (per unun so that all values for each SIH were on a common scale.

The second problem was related to the baseline (resting or sleep period) specimen. Retrospectively, it is apparent that we were too naive initially i believing that the baseline values for all ATCS's would show little variability. In fact, baseline values varied widely from facility to facility. This wide variation made it undesirable to use rest-to-work increments in excretion level of SIH's as a stress indicator. Fig. 1 illustrates in graphic form the problem with such an approach. If one were dealing with only one facility, percent increase in st excretion would be a valid expression of stress. However, when different facilities are involved it is apparent that comparison of increments does not fairly represent the difference in stress levels. For example, the mean level of excretion of st by ATCS's during work at Los Angeles (LAX) Terminal Radar Approach Control (TRACON) did not even come up to the mean level of resting excretion of adrenocorticosteroids of ATCS's at O'Hare ATCT.

By using the product of the adjusted resting and working excretion levels one can assign appropriate importance to both values. These products have been referred to as individual indices of stress, designated as c_{st}, c_e, and c_{ne}. The average of the three individual indices is the composite stress index, C_s.

The steps used in computing C_s are as follows:

1. $\frac{\Sigma x}{n} = \overline{x}$

2. $\frac{\overline{x}_r}{\overline{x}_G} = \overline{x}_{ar}; \frac{\overline{x}_w}{\overline{x}_G} = \overline{x}_{aw}$ (Computed for each SIH)

3. $(\bar{x}_{ar})\,(\bar{x}_{aw}) = c_{SIH}$

4. $C_s = \dfrac{c_{st} + c_e + c_{ne}}{3}$

x = Individual values

n = Number of values

$\bar{x}$ = Mean of individual values

$\bar{x}_r$ = Mean of individual resting values

$\bar{x}_w$ = Mean of individual working values

$\bar{x}_G$ = Grand mean

$\bar{x}_{ar}$ = Adjusted resting value

$\bar{x}_{aw}$ = Adjusted working value

c_{SIH} = Individual index for any SIH

c_{st} = Individual index for 17-KGS

c_e = Individual index for epinephrine

c_{ne} = Individual index for norepinephrine

C_s = Composite stress index

The individual indices were used graphically to produce an equilateral triangle, the area of which is proportional to C_s. The use of the three c-values to construct a triangle is based on a theorem stating that the sum of the lengths of lines joined at an interior point and perpendicular to the sides of an equilateral triangle is equal to the altitude of the triangle.

The c-values are represented as lines originating at a point and diverging at angles of 120°; the length of each line is proportional to the value of each individual index. For simplicity's sake, these lines are called vectors. Lines constructed at right angles to the free ends of the vectors form an equilateral triangle, the altitude of which is equal to the sum of the lengths of the vectors ($c_{st} + c_e + c_{ne}$). Thus, the area of the triangle is proportional to C_s, the average of c_{st}, c_e, and c_{ne} (see Fig. 2, ORD).

The use of these stress indices and the diagram, called the Streng triangle (25), facilitated comparisons of stress at ATC facilities (15).

Several variables assumed to contribute to ATCS stress were represented in this series of studies. Among them were workload, shift rotation patterns, automation (ARTS III), and "other factors." In the following section results are summarized according to those variables.

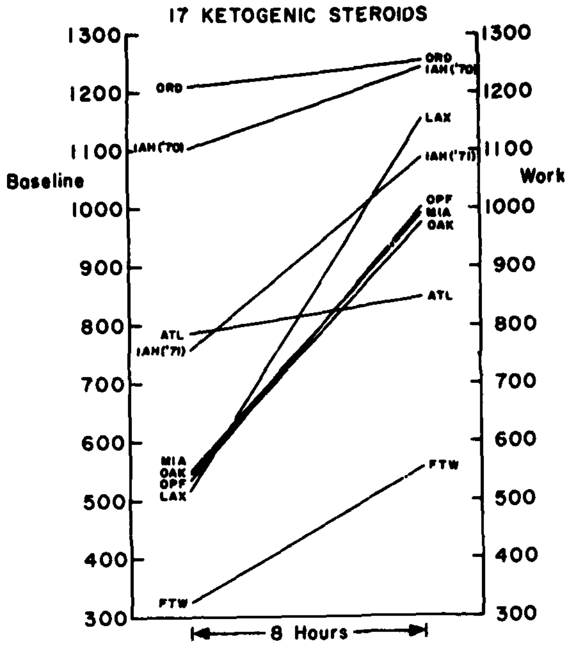

Figure 1. Relationship between baseline (night sleep specimen) and response (8-hour pooled work specimen) at the various facilities. Ordinate is μg 17-KGS (st) per 100 mg of creatinine.

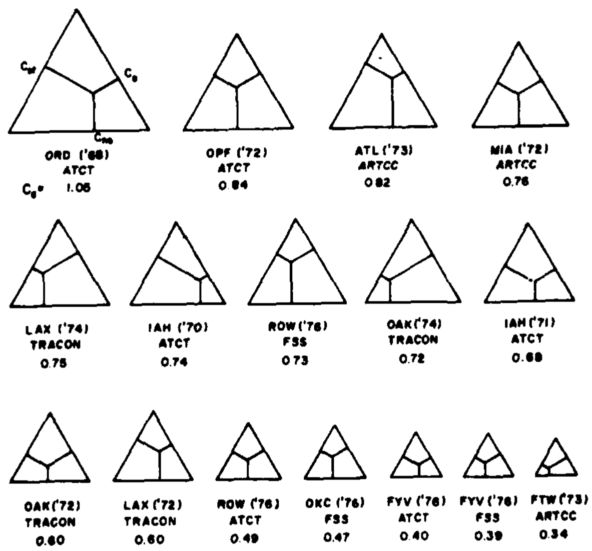

Figure 2. Stress at various ATC facilities represented on Streng diagrams.

RESULTS

A. Workload. Workload is perceived as the principal stressor in ATC; therefore, a series of studies was carried out at ATC facilities having different traffic loads in an attempt to measure physiological responses in ATCS's to those different levels of workload. The first study was carried out at O'Hare ATCT where physiological responses to the heavy-duty evening shift (1600-2400) were compared with responses to the relatively light-duty morning shift (0000-0800). Air operations during the early part of the evening shift commonly were in excess of 200/h; on the morning shift traffic volume was typically about 25 operations/h during the first half of the shift, but increased sharply on weekdays near the end of the shift (dawn) as air cargo flights arrived in Chicago. Each ATCS subject was monitored throughout a full workweek (5 d) on each shift.

When mean HR's on the two shifts were compared, it was evident that workload on the evening shift gave rise to significantly higher HR's in local controllers (cab) and radar controllers (approach and departure) than did the workload on the morning shift (Table II). Ground control and clearance delivery work did not give rise to significantly different HR's on the two shifts (Tables III and IV).

During the busy first half of the evening shift, local control and approach control positions caused ATCS's HR's to be significantly higher than were HR's during work on ground or departure control. On the morning shift such differences were not statistically significant.

The GSR (skin electrical resistance) was also related to workload, being significantly lower on the evening shift than on the morning shift (Fig. 3). The GSR decreases with arousal and increases with relaxation. Increasing relaxation (perhaps somnolence) is shown by the upward trend of mean maximum resistance over the workweek on the morning shift. On the evening shift no such trend was present (Fig. 3).

Blood levels of phospholipids in O'Hare ATCS's were significantly higher than in a group of controls (laboratory workers). Total phospholipids in O'Hare ATCS's exceeded values found in schizophrenics and Navy pilots flying carrier-based combat missions in Vietnam. Phosphatidylglycerol, reported to be a more specific stress indicator than is total phospholipids, showed ORD ATCS's to be stressed significantly more than "normals," but less than combat pilots or schizophrenics (Table V, Fig. 4).

Results of urine analysis (4) for several substances are shown in Tables VI, VII, and VIII. Generally, ATC work was associated with sympathoadrenomedullary stimulation reflected in elevated catecholamine excretion. Recovery to prework levels was accomplished during night/morning sleep following the evening shift but was not complete during day sleep after the morning shift, thus providing evidence of cumulative fatigue over five consecutive midshifts. Adrenocortical hyperactivity was evident only on the morning shift.

ATCS's at Houston Intercontinental Airport (IAH) ATCT, a medium density facility, were studied in 1970 to provide data for comparison with ORD ATCS's (10).

TABLE II. Comparisons Between Morning Shift and Evening Shift

Number of ATC in Comparison	Activity	AVERAGE HEART RATE Evening Shift	Morning Shift	Significance Level .10, .05, .01, or NS (not significant)*
9	Local Control	101.70	82.51	.01
3	Ground Control	100.43	79.93	*
1	Clearance Delivery	90.50	86.00	*
12	Approach Control	90.77	77.23	.01
12	Departure Control	84.88	74.83	.01

* Data not sufficient to make a statistical test.
** Wilcoxon matched pairs signed rank test.

TABLE III. Comparisons* Between Types of Activity During Evening Shift

Number of ATC in Comparison	First Activity	Average Heart Rate	Second Activity	Average Heart Rate	Significance Level .01,.05,.01,or NS***
14	Local Control	94.59	Approach Control	89.24	N.S.
14	Local Control	94.37	Departure Control	84.75	.01
17	Approach Control	88.55	Departure Control	84.57	.05
4	Ground Control	99.20	Local Control	105.72	**
2	Ground Control	98.60	Departure Control	95.10	**
3	Ground Control	97.56	Approach Control	94.23	**

* Data not sufficient for comparisons among other activities.
** Data not sufficient to make a statistical test.
*** Wilcoxon matched pairs signed rank test.

TABLE IV. Comparisons* Between Types of Activity During Morning Shift

Number of ATC in Comparison	First Activity	Average Heart Rate	Second Activity	Average Heart Rate	Significance Level .01,.05,.01,or NS***
9	Local Control	81.51	Approach Control	79.51	N.S.
9	Local Control	81.61	Departure Control	77.89	N.S.
11	Approach Control	75.95	Departure Control	74.16	N.S.
6	Ground Control	79.18	Local Control	83.20	N.S.
6	Ground Control	78.47	Departure Control	79.28	N.S.
4	Ground Control	76.30	Approach Control	80.42	**
5	Clearance Delivery	84.02	Local Control	83.98	**
3	Clearance Delivery	83.76	Ground Control	83.90	**
4	Clearance Delivery	83.27	Approach Control	78.82	**
4	Clearance Delivery	85.45	Departure Control	81.22	**

* Data not sufficient for comparisons among other activities.
** Data not sufficient to make a statistical test.
*** Wilcoxon matched pairs signed rank test.

TABLE V. Comparison of Plasma Phospholipids of Air Traffic Controllers and a Normal Population

	µM Phospholipid P/liter				% Distribution		
	Total Phospholipid	Phosphatidyl Ethanolamine	Phosphatidic Acid	Phosphatidyl Glycerol	Phosphatidyl Ethanolamine	Phosphatidic Acid	Phosphatidyl Glycerol
Air Traffic Controllers							
A. Routine Shifts N=25	*3042 ±84	**50.7 ±2.0	*20.7 ±0.7	*45.0 ±2.2	1.68 ±.07	0.69 ±.03	**1.49 ±.07
B. Exceptional Situations N=15	*3272 ±104	*62.4 ±3.6	*20.6 ±1.5	*43.4 ±2.6	1.91 ±.10	0.63 ±.04	1.32 ±.07
Normal Population N=32	2272Δ ±84	41.0 ±2.5	14.2 ±.9	24.7 ±2.0	1.83 ±.10	0.65 ±.04	1.12 ±.09

* P (t) < .001 when compared to normal population.
** P (t) < .01 when compared to normal population.
Δ Mean ± S.E.

TABLE VI. Summary of SIH Excretion-ORD ATCS's

Time	Epinephrine µg/100 mg Creatinine		Norepinephrine µg/100 mg Creatinine		17-OHCS µg/100 mg Creatinine	
	Evening Shift	Morning Shift	Evening Shift	Morning Shift	Evening Shift	Morning Shift
Work Period (4th h)	1.30	1.07*	3.87	3.24*	351	204**
Work Period (7th h)	1.96	2.05	5.57	6.30	269	331**
	(+0.66)	(+0.98)	(+1.70)	(+3.06)*	(—82)	(+127)**
	P < .05	P < .01	P < .05	P < .01	P < .01	P < .01
Postwork Period	0.59	1.12**	2.59	4.68**	224	325**
	(−1.37)	(−0.93)	(−2.98)	(−1.62)	(—45)	(—6)
	P < .01	P < .01	P < .01	P < .05	P < .01	NS

For each urinary variable the value of the mean change over each time interval (that between the 4th and 7th hours of the work period and that between the 7th hour of the work period and the end of the sleep period) appears in parentheses and is followed by its probability value. Where there was a statistically significant difference between corresponding evening and night values, asterisks appear beside the night value (*P < .05; **P < .01).

TABLE VII. Data Summary-Control Subjects (Biomedical Team)

Time	Epinephrine µg/100 mg Creatinine		Norepinephrine µg/100 mg Creatinine		17-OHCS µg/100 mg Creatinine	
	Evening Shift	Morning Shift	Evening Shift	Morning Shift	Evening Shift	Morning Shift
Work Period (4th h)	0.66	0.76	2.89	2.85	380	242**
Work Period (7th h)	0.49	0.52	2.91	2.86	352	270
	(—0.17)	(—0.24)	(+0.02)	(+0.01)	(—28)	(+28)
	NS	NS	NS	NS	NS	NS
Postwork Period	0.62	0.78	2.83	3.51	195	347**
	(+0.13)	(+0.26)	(—0.08)	(+0.65)	(—157)	(+77)*
	NS	NS	NS	NS	P < .05)	NS

For each urinary variable the value of the mean change over each time interval (that between the 4th and 7th hours of the work period and that between the 7th hour of the work period and the end of the sleep period) appears in parentheses and is followed by its probability value. Where there was a statistically significant difference between corresponding evening and night values, asterisks appear beside the night value (*P < .05; **P < .01).

TABLE VIII. Nocturnal Wakefulness Vs. Nocturnal Sleep

	Epinephrine µg/100 mg Creatinine		Norepinephrine µg/100 mg Creatinine		17-OHCS µg/100 mg Creatinine	
Test Circumstance	Control Group	Test Group	Control Group	Test Group	Control Group	Test Group
Nocturnal Sleep	0.62	0.59	2.83	2.59	195	224
Nocturnal Wakefulness	0.52	2.05**	2.86	6.30**	270	331
Difference	—0.10	+1.46**	+0.03	+3.71**	+75	+107
P	NS	< .01	NS	< .01	< .01	< .01

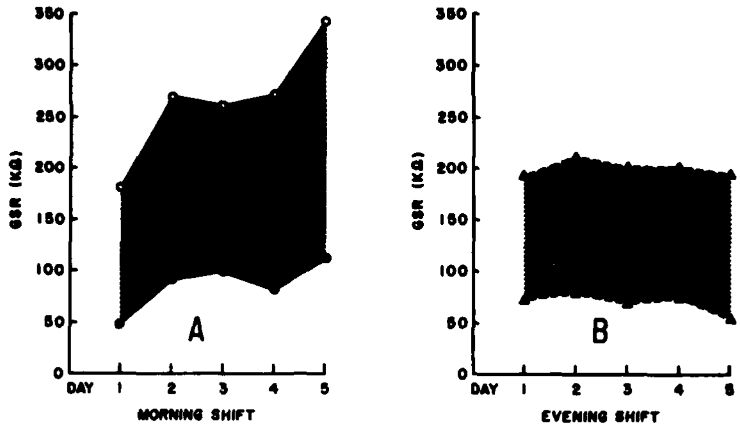

Figure 3. Galvanic skin response on (A) the 5-day morning shift and (B) the 5-day evening shift. The daily values are the means of the maximum and minimum resistances, respectively. (A) shows that the upward trend of mean maximum resistance continues over the 5-day period. Such a trend is not evident for (B).

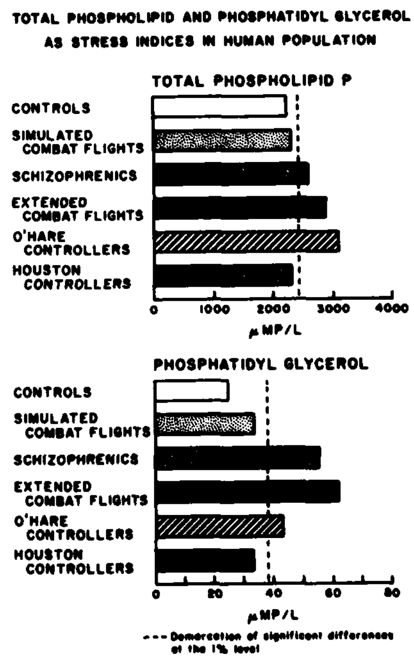

Figure 4. Graph of total phospholipid phosphorus and phosphatidyl glycerol for five groups of subjects. Controllers show a higher titer of all phospholipids than any of the other groups but their phosphatidyl glycerol level (a more specific and less variable index than total phospholipid) exceeds only those of the normal population and simulated combat flight group.

There were similarities between ORD and IAH (1970) ATCT's as well as differences. Both ATCT's were located at air carrier airports; ATCS's at both facilities were on the "straight-5" shift-rotation pattern; ATCS's at both towers worked cab and radar positions. The two facilities differed mainly in regard to traffic load. ORD commonly had 2,000 operations/d; IAH had about 700 operations/d. The ATC slowdown of 1968 was in effect during the period of the study at ORD. Traffic was normal at IAH in July 1970; however, IAH ATCS's had just concluded a "sick out" when our study began and disciplinary actions were being taken against several ATCS's. IAH ATCS's showed quantitatively less total stress than did ORD controllers; qualitatively, however, ATCS's at the two towers resembled each other. The heavy-duty shifts at both towers were associated with elevated excretion of SIH's, reflecting arousal commensurate with the workload. Comparisons of ORD and IAH ATCS's are shown in Tables IX, X, and XI.

Opa Locka Airport (OPF) in surburban Miami, Florida, is an extremely busy general aviation airport. The ATCT is a nonradar facility open 16 h/d. At the time of our study OPF ATCT ranked 10th in the nation in annual number of operations. Fourteen ATCS's were each monitored on the day shift (0800-1600) (12).

OPF ATCS's showed a pronounced sympatho-adrenomedullary response to the heavy workload. RT was significantly related to c_e and C_s. Workload was related to c_{ne} with weak significance ($p < 0.05$) and not significantly related to c_{st} (Table XII and Figs. 5-8).

Studies of ATCS response to ATCT work were completed with observations at two low-density towers in Fayetteville, Arkansas (FYV), and Roswell, New Mexico (ROW) (15). ROW ATCT ranked 275th (ca. 93,000 operations/yr) and FYV ranked 404th (ca. 40,000 operations/yr) nationally; at the time of these studies there were 424 active U.S. ATCT's.

Arousal, as evidenced by rest-to-work increments in all three urinary SIH's, was evident in ROW and FYV ATCS's. However, the levels of SIH's in urine were quantitatively less than at ORD, OPF, and IAH (Figs. 2 and 9).

Epinephrine excretion is also linearly related to annual traffic count. In Fig. 9, e excretion is graphed against annual traffic count at FYV, ROW, IAH, OPF, and ORD. Traffic count at ORD has been adjusted to reflect the fact that a controller at ORD did not handle the entire traffic load. ORD operated as "two" airports with separate ground controllers and local controllers for the two sides of the airport; thus, only half the traffic load impinged on a single controller. When adjustment was made for this arrangement at ORD, the plotted point fell very near the regression line.

Steroid excretion is not generally related with statistical significance to acute ATC workload. Steroid excretion is probably related to long-term stressors that may or may not be connected with ATC work. It is not uncommon to see a decrease in a controller's st excretion in the at-work urine specimen, probably reflecting relief through work-related distraction from some off-the-job stressor.

TABLE IX. Urinary Excretion Products Expressed as Percent of Baseline Values

ORD VS. IAH*

Shift	Epi	Norepi	Corticosteroid
Day - 1st 1/2	-1.04 N.S.**	0.31 N.S.	1.39 N.S.
Day - 2nd 1/2	1.85 N.S.	2.43 ≤ .05	2.40 ≤ .05
Mid - 1st 1/2	4.20 ≤ .01	1.84 N.S.	-0.16 N.S.
Mid - 2nd 1/2	4.56 ≤ .01	5.15 ≤ .01	-1.30 N.S.
Mid - Postwork	2.42 ≤ .05	3.53 ≤ .01	1.05 N.S.

**t test of a difference between two sample means. The chart is a list of t-values, followed by level of significance.

***Negative numbers mean that ORD values are lower than IAH values.

TABLE X. Comparisons Between ORD and IAH Heart Rates

Activity	Average Heart Rate ORD	IAH	Significance Level*
Midshift (0200 to 0600)	72	77	N.S.
Day Shift (1000 to 1400 ORD) vs. (1700 to 2100 IAH)	83	90	.05
Midshift			
CAB Position	78	81	N.S.
Radar Position	75	78	N.S.
Supervisor Position	76	76	N.S.
**Prework	80	86	.05
Day Shift			
CAB Position	81	95	.002
Radar Position	84	87	N.S.
Supervisor Position	86	90	N.S.
**Prework	84	95	.01

* Mann-Whitney U Test
** One Minute heart rate determination at the time of instrumentation.

TABLE XI. Plas.. Phospholipids in μM P/Liter
ORD Vs. IAH ATCS's and Controls

	Total Lipid Phosphorus	Lecithin	Phosphatidyl Ethanolamine	Cardiolipin	Phosphatidic Acid	Phosphatidyl Glycerol	Number of Subjects	Number of Determinations
ORD ATCS's (1968)	3128*	2144*	55.1*	32.2*	20.7*	44.4*	21	40
S.E.	±67	±55	±2.0	±1.4	±.7	±1.7		
IAH ATCS's (1970)	2412	1676	32.6	21.5	11.5	33.8	19	53
S.E.	±28	±25	±.6	±.3	±.3	±.6		
Control (Non-ATCS) Population	2237	1557	40.5	29.2	13.4	26.	37	37
S.E.	±68	±58	±2.0	±1.1	±.8	±1.7		
Plasma Phospholipids in % Distribution								
ORD ATCS's (1968)		68.4	1.77*	1.04*	0.67*	1.43	21	40
S.E.		±.5	±.06	±.04	±.02	±.05		
IAH ATCS's (1970)		69.4	1.35	0.90	0.48	1.41	19	53
S.E.		±.3	±.02	±.02	±.02	±.03		
Control (Non-ATCS) Population		69.2	1.80	1.32	0.61	1.21	37	37
S.E.		±.7	±.07	±.05	±.03	±.07		

* $P_{(t)} < .001$ ORD Vs. IAH

TABLE XII. Correlation Coefficients of C_s, c_{st}, c_e, and c_{ne} and Workload in OPF ATCS's

	c_{st}	c_e	c_{ne}	Workload (transmission time)
C_s	.70**	.81***	.88***	.64*
c_{st}	-	.59*	.38	.19
c_e	-	-	.52	.77**
c_{ne}	-	-	-	.55*

* $P \leq .05$
** $P \leq .01$
*** $P \leq .001$

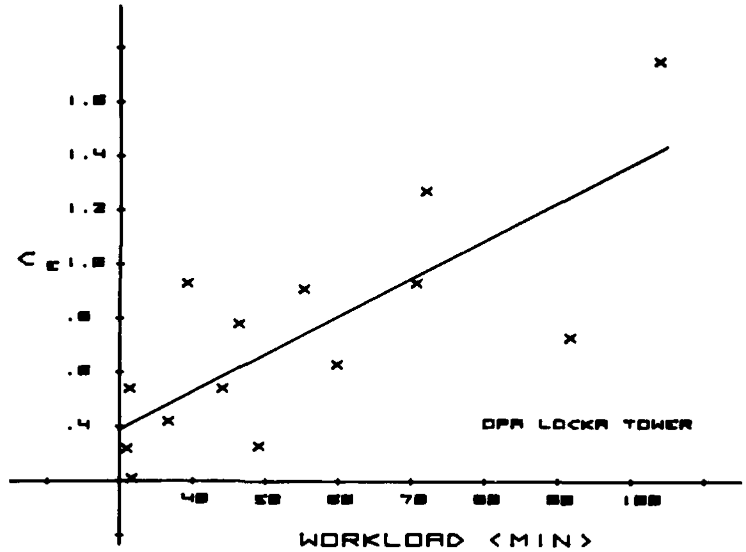

Figure 5. Relationship between c_e and workload represented by minutes of radio communication time.

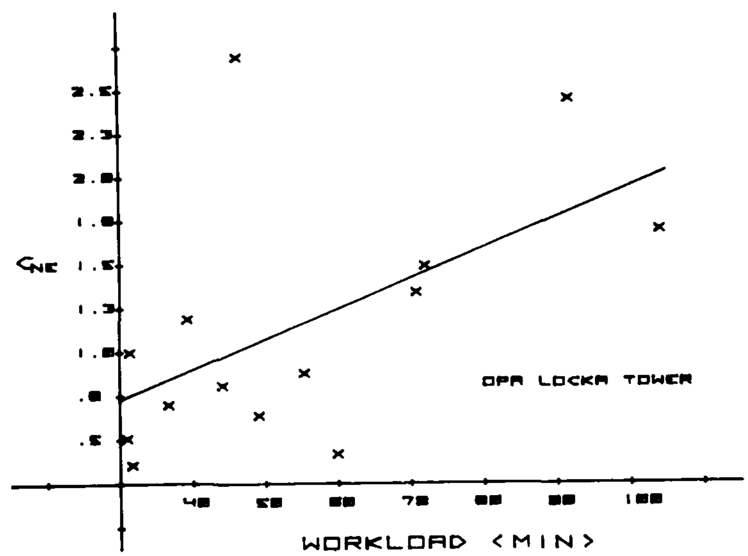

Figure 6. Relationship between c_{ne} and workload represented by minutes of radio communication time.

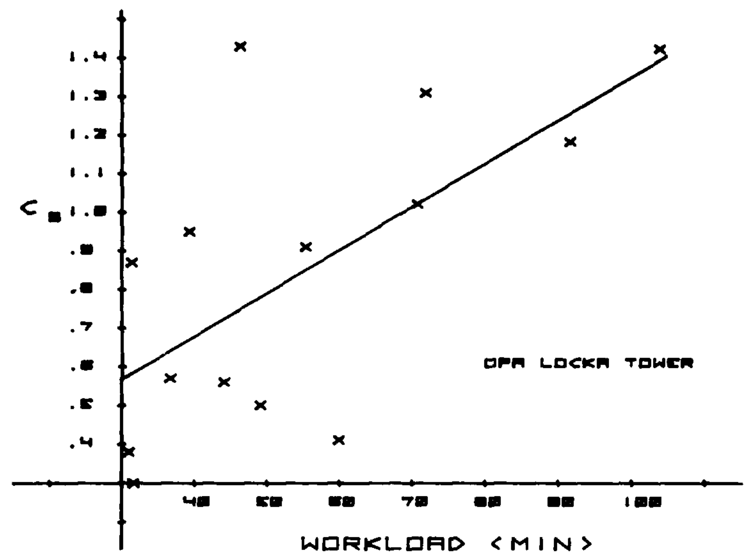

Figure 7. Relationship between C_s and workload represented by minutes of radio communication time.

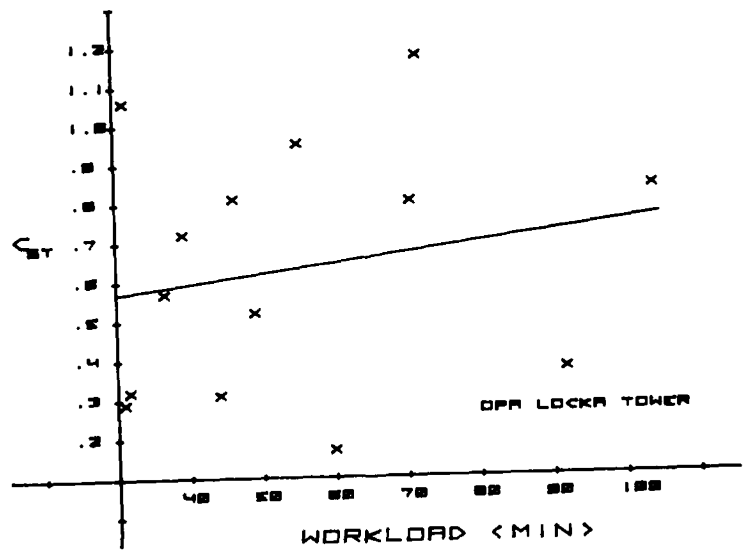

Figure 8. Relationship between c_{st} and workload represented by minutes of radio communication time.

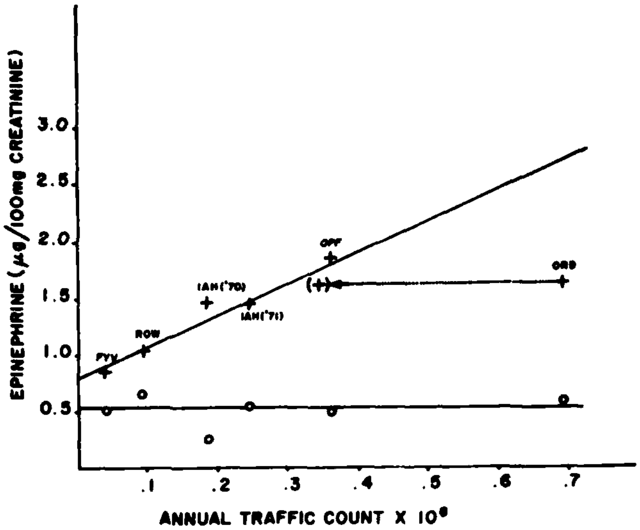

Figure 9. Graph of annual traffic count (in millions of operations) vs. mean urinary excretion levels of epinephrine of controllers at the various facilities. Crosses represent on-duty excretion levels of epinephrine; circles represent corresponding resting levels (ORD represented at actual traffic count and adjusted value (+) as described in text).

B. Shift Rotation Patterns and Sleep. With any activity that requires 24-h coverage 7 d/wk, the pattern of rotation of watches is of concern. Time and attendance requirements usually constrain employees to work 8 h/d for 5 consecutive days, complicating the scheduling of the work force.

In ATC two basic work shift rotation patterns have evolved, the "straight 5" and the "2-2-1." On the "straight-5" shift-rotation pattern an ATCS works two 5-d weeks on the day shift (usually 0800-1600), two 5-d weeks on an evening shift (usually 1600-2400) and one 5-d week on the midshift (0000-0800). A 2-d time-off period comes at the end of each 5-d workweek. Of course, shifts may start and end on any day of the week.

The 2-2-1 shift-rotation pattern calls for the ATCS to work a different shift each day of the 5-d workweek. Typically, an ATCS would work from 1600 to 2400 on day 1, 1400 to 2200 on day 2, 0800-1600 on day 3, 0700-1500 on day 4, and 0000-0800 on day 5. Thus, the 2-2-1 pattern involves compression of 40 h of work into an 88-h period allowing 80 h off duty between workweeks. On the straight 5, 40 h of work is spread over 104 h, 96 h, or 112 h, depending on shift change combinations. Over five workweeks (four intervening off-duty periods) encompassing the full straight-5 shift rotation, an ATCS on the 2-2-1 gets a total of 320 h "weekend time," whereas an ATCS on the straight-5 gets a total of 240 h "weekend time"--a difference of 80 h. These patterns are diagramed in Fig. 10.

In 1970, IAH ATCT was on the straight-5 shift pattern. ATCS's at IAH worked a week of evenings, then a week of days, another week of evenings, another week of days, then a week of midshifts. This was not the work pattern preferred by most ATCS's at IAH and considerable labor-management tension was evident as a result. In 1971 the facility returned to the 2-2-1 pattern, thus affording us an opportunity to study essentially the same group of ATCS's under both shift-rotation patterns (11).

While the ATCS's liked the 2-2-1 shift pattern, management felt that the "quick turnaround" inherent in the pattern (Fig. 10) did not allow sufficient time for rest between work periods, thus leading to a potential for increased error rate and excessive use of sick leave because of fatigue.

Nineteen controllers volunteered to participate in the study: 12 were journeymen, 5 were supervisors, and 2 were trainees; 12 of them had served as subjects on the previous 1970 project. The techniques and measurements employed were the same as those used on the 1970 project. Briefly, the ECG was recorded continuously on tape throughout every work period. Urine was collected by each subject when he arose each morning (Specimen No. 1), during the first 4 h (Specimen No. 2), and the last 4 h (Specimen No. 3) of each shift. Blood specimens were taken from each subject when he began his workweek. Urine was analyzed for e, ne, st, and cr. Blood plasma was analyzed for total phospholipid and phosphatidylglycerol.

Table XIII shows a comparison of HR's of ATCS's between various work positions during day/evening work and midshift work on the two shift-rotation patterns. Statistically significant differences occurred on the midshift with the average HR being higher on the 2-2-1 rotation.

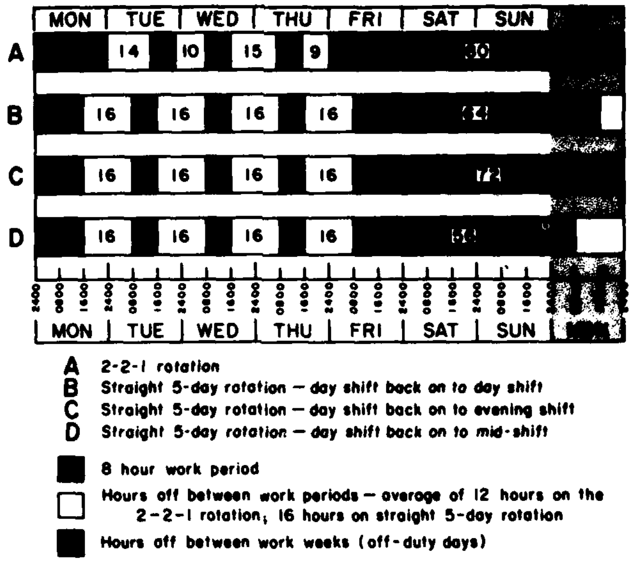

Figure 10. Graphic representation of a week on the 2-2-1 and 5-day rotations. The weeks shown begin on Monday; however, a controller's workweek may start on any day and his weekend will necessarily be days other than Saturday and Sunday.

Table XIII shows, where data are sufficient for statistical testing, that there are no significant differences during day work between HR's on the two shift-rotation patterns for the various work positions. Table XIV shows only one point of statistically significant difference between midshift positions on the two rotations: approach control radar. Most of the midshift data in Table XIV are insufficient for statistical comparison because of the fact that only one controller was in the cab and one in the radar room. When the different positions are considered separately, data for each of them become scanty.

Within the group on the 2-2-1 rotation there are no points of statistically significant difference in HR's between work positions.

There were no significant differences in urinary e excretion by the two groups during day work (Table XV). A significantly elevated excretion of e occurred during nocturnal sleep by the group on the 2-2-1 rotation; however, e excretion over an entire week of day work (straight 5) was slightly, but insignificantly, higher than e excretion of a 5-d week on the 2-2-1 rotation.

When the midshifts were similarly compared, the excretion of e was significantly elevated in the 2-2-1 group, except during day sleep when the two groups' e excretion was equal.

Norepinephrine excretion was significantly greater during day work on the straight-5 rotation than on the 2-2-1 rotation. There was no significant difference in ne excretion during nocturnal sleep on the two rotation patterns.

There were no significant differences in ne excretion by controllers on the midshifts of the two rotation patterns. Likewise, ne excretion did not differ significantly during day sleep on the two rotation patterns.

17-KGS excretion was significantly higher during the first half of the midshift on the 2-2-1 rotation than it was during the comparable period on the 5-d rotation. That trend was reversed, however, during day sleep when st excretion was significantly elevated in the straight-5 group. When the st data were expressed as percent of the baseline (night sleep Specimen D-3), adrenocortical responsiveness was seen to be significantly higher in the 2-2-1 group during the first half of the midshift and for the whole week that it was on the midshift in the straight-5 group. Day work was characterized by significantly elevated st excretion by the straight-5 group. The difference between the groups was not seen, however, during nocturnal sleep. When a week of day work on the straight-5 rotation was compared to day/evening work on the 2-2-1 (Specimen D-4), it was apparent that the straight-5 rotation was significantly more stressful than was the 2-2-1 rotation. Adrenocortical responsiveness (percent baseline) was not significantly different in the two groups.

Table XVI shows that there are no points of statistically significant difference between the two work schedules as far as total plasma phospholipids are concerned. However, the two shift-rotation patterns can be differentiated significantly on the basis of phosphatidylglycerol levels in the controllers' plasma specimens, with the higher value occurring in connection with both the day shift and midshift of the straight-5 rotation. When the change in phospholipid levels over the workweeks (postwork minus prework levels) on the two rotation patterns were compared, there were no points of significant difference in either total phospholipid or phosphatidylglycerol levels.

TABLE XIII. Comparison of Heart Rates at Different Work Positions 5-Day Vs. 2-2-1 Rotations-IAH ATCT

Work Position	Average Heart Rate: 5-Day Rotation	Average Heart Rate: 2-2-1 Rotation	p***
Midshift			
Radar	73	81	$\leq$ 0.01
Cab	76	83	$\leq$ 0.02
Supervisor	76	80	**
Prework	78	83	N.S.
All positions	70	81	$\leq$ 0.01
Daywork			
Radar	81	81	N.S.
Cab	81	83	N.S.
Supervisor	85	81	**
Prework	81	83	N.S.
All positions	81	81	N.S.

** Data insufficient for statistical test.
*** Wilcoxon matched signed rank test.

TABLE XIV. Comparison of Heart Rates During Midshift Work on 5-Day and 2-2-1 Rotations

Work Position	Average Heart Rate: 5-Day Rotation	Average Heart Rate: 2-2-1 Rotations	p***
Approach control radar	73	81	$\leq$ 0.02
Departure control radar	75	81	**
Coordinator radar	82	86	**
Supervisor radar	77	78	**
Local control cab	75	75	**
Ground control cab	79	84	**
Clearance delivery & data	79	84	N.S.

** Data not sufficient for statistical test.
*** Wilcoxon matched pairs signed rank test.

TABLE XV. Urine Chemistry
5-Day Vs. 2-2-1 Rotation
IAH ATCT

	Rotation Pattern	Epinephrine	Norephinephrine	17-KGS	17-KGS % Baseline
D1	5*	1.71 ± 0.95	3.65 ± 0.89	1602.79 ± 537.70	191.56 ± 66.56
	2**	1.41 ± 0.54	3.10 ± 0.81	1144.92 ± 293.77	168.69 ± 47.19
	P	N.S.	≦ 0.01	≦ 0.01	N.S.
D2	5	1.47 ± 0.67	3.98 ± 1.06	1463.00 ± 476.35	179.38 ± 80.68
	2	1.33 ± 0.51	2.95 ± 0.63	1007.93 ± 317.22	145.11 ± 34.70
	P	N.S.	≦ 0.05	≦ 0.01	N.S.
D3	5	0.27 ± 0.10	2.44 ± 1.11	863.48 ± 296.92	100.00
	2	0.55 ± 0.21	2.18 ± 0.44	755.91 ± 222.96	100.00
	P	≦ 0.01	N.S.	N.S.	
D4	5	1.59 ± 0.80	3.81 ± 0.83	1532.82 ± 494.93	185.40 ± 71.98
	2	1.37 ± 0.49	3.02 ± 0.65	1087.83 ± 270.31	158.17 ± 36.26
	P	N.S.	≦ 0.01	≦ 0.01	N.S.
M1	5	0.70 ± 0.42	2.76 ± 0.34	759.84 ± 230.46	94.25 ± 43.74
	2	1.41 ± 0.54	3.10 ± 0.81	1144.92 ± 293.77	168.69 ± 47.19
	P	≦ 0.01	N.S.	≦ 0.01	≦ 0.01
M2	5	0.90 ± 0.54	2.92 ± 0.60	1056.90 ± 303.07	132.13 ± 57.70
	2	1.33 ± 0.51	2.95 ± 0.63	1007.93 ± 317.22	145.11 ± 34.70
	P	≦ 0.01	N.S.	N.S.	N.S.
M3	5	0.84 ± 0.64	2.49 ± 0.64	1346.03 ± 398.32	169.91 ± 66.35
	2	0.84 ± 0.71	2.36 ± 0.52	755.91 ± 227.96	150.34 ± 65.47
	P	N.S.	N.S.	≦ 0.01	N.S.
M4	5	0.82 ± 0.35	2.85 ± 0.45	1188.88 ± 249.34	116.26 ± 52.03
	2	0.93 ± 0.49	2.61 ± 0.77	1087.83 ± 270.31	158.17 ± 36.26
	P	N.S.	N.S.	N.S.	≦ 0.05

D-1 = Day shift specimen #2
D-2 = Day shift specimen #3
D-3 = Day shift specimen #1 (night sleep)
D-4 = All #2 and #3 specimens for whole workweek

M-1 = Midshift specimen #2
M-2 = Midshift specimen #3
M-3 = Midshift specimen #1 (day sleep)
M-4 = All #2 and #3 specimens for whole workweek

* 5-Day rotation
**2-2-1 rotation

TABLE XVI. Plasma Phospholipids
5-Day Vs. 2-2-1 Rotation
IAH ATCT

		Total Lipid Phosphorus	Phosphatidyl Glycerol
Prework	5-Day	2406 ± 250.19 (s.d.)	34.23 ± 4.16 (s.d.)
	2-2-1	2211 ± 186.43	27.48 ± 3.62
	p*	N.S.	$p \leq 0.01$
Postwork	5-Day (Day Shift)	2242 ± 226.70 (s.d.)	35.16 ± 5.44 (s.d.)
	2-2-1	2222 ± 181.60	28.42 ± 3.49
	p	N.S.	$p \leq 0.01$
Postwork	5-Day (Midshift)	2392 ± 216.44 (s.d.)	33.19 ± 5.35 (s.d.)
	2-2-1	2227 ± 165.88	29.07 ± 3.70 (s.d.)
	p	N.S.	$p \leq 0.01$
Prework/ Postwork Differences	5-Day (Day Shift)	14.40 ± 51.82	1.47 ± 3.50
	2-2-1	26.80 ± 41.60	0.80 ± 5.37
	p	N.S.	N.S.
Prework/ Postwork Differences	5-Day	-13.92** ± 66.46	-1.03 ± 4.34
	2-2-1	16.00 ± 46.63	1.59 ± 5.30
	p	N.S.	N.S.

* Paired t test
** Prework values higher than postwork values

Studies were carried out at Atlanta (ATL) and Fort Worth (FTW) Air Route Traffic Control Centers (ARTCC) to examine further the relationship of stress to shift-rotation pattern. ATL was on the straight-5 shift pattern and FTW was on the 2-2-1 (13). These two ARTCC's were chosen for comparison because of several similarities, thus reducing the variables that might enter into differences in stress. They have similar climates, size, traffic loads, and relationships to the cities for which they are named.

Twenty-three male ATCS's at ATL and 29 at FTW volunteered to serve as subjects. Twenty-three of the FTW controllers were on the 2-2-1 rotation schedule and six were on the straight-5 pattern. Data on the 23 FTW controllers on the standard 2-2-1 pattern were compared with data from ATL controllers on the straight-5 rotation.

Pooled urine collections were made by every subject throughout each 8-h work period for one 5-d workweek. Controllers at ATL made urine collections on the same shift for 5 d. Seven ATL subjects were on the midshift, seven were on the day shift, and nine were on the evening shift.

At FTW, because of the daily change of work periods, urine collections were made on more than one shift by each of the 23 subjects on the 2-2-1 pattern. Ten FTW controllers worked all three shifts (day, midshift, and evening) and 13 worked days and evenings only.

Subjects at both facilities collected urine in the manner previously described.

Physiological stress among FTW controllers is measurably less than among ATL controllers (Fig. 2). Since the FTW ARTCC was on the 2-2-1 rotation schedule it is clear that, in and of itself, there is no physiological support for the conviction that the 2-2-1 schedule is more taxing than the 5-d schedule to the individual controller. However, it would be equally unjustifiable to consider the 2-2-1 schedule necessarily--or always--superior to the 5-d schedule. Operationally important differences probably are minimal.

Table XVII shows the comparison of resting and working values for st, e, and ne at ATL and FTW. There were no significant differences in e excretion during sleep between the two facilities. At each of the facilities, however, st, e, and ne excretion was greatest during day sleep following midshift work. Excretion of st and ne by ATL controllers during sleep (day or night) was significantly greater than the output of those stress indicators by FTW controllers.

Table XVII shows that e excretion during work was not significantly different on any shift at ATL and FTW. Excretion of ne was significantly higher at ATL than at FTW on all three shifts. However, st excretion on the day and evening shifts was significantly higher at ATL than at FTW; the difference in st excretion during the midshift work was insignificant.

With regard to the amount of sleep obtained on the two schedules, the differences again are minimal. At IAH, where essentially the same group was studied on the two rotation patterns, the study showed that controllers on the 5-d rotation slept significantly longer at night prior to day shifts than they did in the day prior to midshifts. These same ATCS's on the 2-2-1 rotation slept significantly

TABLE XVII. Between-Group Comparisons of Resting and Working Values for Urinary Metabolites From ATL and FTW Controllers

Resting Values

	17-KGS			e			ne		
	DS*	NS**	NS***	DS	NS	NS	DS	NS	NS
ATL	987.3	533.2	831.8	0.52	0.35	0.38	4.47	2.56	3.55
FTW	429.7	284.2	362.8	0.73	0.52	0.53	1.28	1.15	1.16
P	≤ 0.05	≤ 0.01	≤ 0.01	N.S.	N.S.	N.S.	≤ 0.01	≤ 0.01	≤ 0.01

Working Values

				Shift					
	Mid	Day	Evening	Mid	Day	Evening	Mid	Day	Evening
ATL	469.1	1193.1	877.3	0.84	1.17	1.11	3.88	4.45	5.44
FTW	332.3	700.9	499.9	0.78	1.55	1.25	1.28	2.19	2.08
P	N.S.	≤ 0.01	≤ 0.01	N.S.	N.S.	N.S.	≤ 0.01	≤ 0.01	≤ 0.01

* DS = Day sleep, midshift work
** NS = Night sleep, day shift work
*** NS = Night sleep, evening shift work

less prior to work than they did prior to day work on the 5-d rotation; however, the one midshift included in the 2-2-1 schedule substantially lowered the average amount of sleep because most ATCS's took only a short nap prior to that single midshift (Table XVIII).

In a sense, every day on the 2-2-1 schedule is a quick turnaround day. ATCS's on the 2-2-1 shift pattern never have 16 h off duty between watches. At IAH, the amount of sleep taken prior to day 2 was not significantly different for the two rotation patterns; on day 3 ATCS's on the straight-5 pattern slept an average of 57 min more than ATCS's on the 2-2-1, prior to day 4 the group on the straight-5 rotation slept 1 h and 11 min longer, and prior to day 5 the controllers on the straight-5 rotation slept 4 h and 40 min longer. On a whole week basis, when IAH controllers were doing day work on the straight-5 rotation, they slept an average of 1 h and 36 min longer per night than they did a year later on the 2-2-1 rotation. However, when the single midshift is not included in the comparison, on the 2-2-1 rotation they slept an average of 18 min more than they did the first 4 d of the straight-5 rotation. When a week of work on the 2-2-1 rotation is compared with a week of midshifts, it develops that the 2-2-1 group slept an average of 1 h and 2 min more per night than they did on five straight midshifts.

In order to examine further questions regarding the amount of sleep obtained in connection with the 5-d and 2-2-1 shift schedules, a study was carried out by a questionnaire sent to ATCS's in 35 ARTCC's in the contiguous 48 states (22).

This survey was conducted with the cooperation of the National Headquarters Office of the Professional Air Traffic Controllers Organization (PATCO). Letters requesting volunteers to participate for 5 weeks in the study were sent to the ARTCC's by PATCO's Director of Labor Relations. Sleep logs were then distributed by PATCO local officials to controller-volunteers. Completed sleep logs were returned to PATCO headquarters for forwarding to CAMI for analysis; thus, complete anonymity of volunteers was insured.

One hundred and eighty-five completed questionnaires were returned. Thirty-two of the respondent controllers worked the 2-2-1 rotation schedule, and 132 worked the straight-5 schedule. Twenty-one worked rotation schedules different from the 2-2-1 and straight-5 rotation schedules; data from this group were excluded.

On the basis of a 7-d week (including 2 days off), the average amount of sleep obtained by controllers on the 2-2-1 rotation schedule did not differ significantly from that obtained by controllers working the straight-5 rotation schedule (Table XIX). However, when the 5-d workweek (not including 2 days off) was considered, the amount of sleep obtained on the two rotation schedules was significantly different. On the average, controllers working the straight-5 rotation schedule obtained 18 min more sleep per 24-h period ($p < .01$) than did controllers working the 2-2-1 rotation schedule. Again, the difference was clearly caused by the small amount of sleep obtained by controllers on the 2-2-1 rotation schedule prior to the one midshift. On both rotation schedules, the greatest amount of sleep was obtained in association with the evening shift, while the least amount of sleep was associated with the midshift.

This study, conducted on a more extensive basis than the others preceding it, generally confirmed the findings of those earlier studies; i.e., the 2-2-1

TABLE XVIII. Comparison of Hours of Sleep Prior to Work

Shift Rotation Pattern		Workday 1	2	3	4	5	Weekly Average (Derived from all participating subjects)
5-Day (Days)		7:04	6:58	6:56	7:11	7:10	6:58
	Δ	1:03	0:09	0:57	1:11	4:40	0:53
	p*	≤ 0.05	N.S.	≤ 0.05	≤ 0.05	≤ 0.01	≤ 0.01
2-2-1		8:07	6:49	5:59	6:00	2:30	6:05
	Δ	2:08	1:15	0:35	0:11	3:50	0:06
	p**	N.S.	N.S.	N.S.	N.S.	≤ 0.01	N.S.
5-Day (Mid)		5:59	5:34	5:24	5:49	6:20	5:59

* Significance level of difference between values on day shifts and 2-2-1 rotation.
** Significance level of difference between values on midshifts and 2-2-1 rotation.

TABLE XIX. Comparison of Average Number of Hours Slept in Connection With the Various Shifts (and Days Off) on the Two Rotation Schedules-Survey of ARTCC ATCS's

Shift	Rotation Schedule	
	5-Day	2-2-1
Day	6.0	5.8 *
Evening	7.4	7.6
Mid	5.2	3.5 **
Days Off	7.7	7.9
Average, 5-Day Workweek	6.4	6.1 **
Average, 7-Day Week	7.1	7.0

* $p < .05$

** $p < .01$

shift-rotation schedule is not, to say the least, inherently a more disruptive routine because of sleep loss than is the straight 5. In fact, the average amount of sleep reported for the workweek by ATCS's on either rotation is somewhat more than values reported for rotating shift workers in other industries who average less than 6 h of sleep per 24 h (1).

C. Automation. "Manual" radar consists of a display of primary or transponder returns that give information about azimuth, range, and speed of aircraft. Altitude and aircraft identification are obtained verbally by radio contact with pilots. Thus, some degree of uncertainty about aircraft separation attends manual control.

Computer-generated radar displays exemplified by the Automated Radar Terminal System-III (ARTS-III) supplies the air traffic controller with positive aircraft identification and three-dimensional data regarding location and rate of movement in the airspace, thus contributing enormously to safety. ARTS-III also supposedly eases the workload of controllers by reducing intercontroller coordination, flight strip activity, radio communication with pilots, and activity related to radar and radio adjustments. ARTS-III differs operationally from the old radar system in several ways. Controllers do not carry out as much "face to face" coordination with each other but communicate by telephone. ARTS-III demands a great deal of keyboard work in use of the computer. The consoles are arranged in islands equipped with horizontal cathode ray tubes, and the lighting level is somewhat higher in the new TRACON facilities than it was in the old ones. Many other environmental changes accompanied ARTS-III: temperature is more closely controlled, decor is pleasant, and meal facilities are improved. Parking is close by, whereas it had been in fairly remote areas at most towers.

The effect of ARTS-III on controller stress was estimated from pre-ARTS-III and post-ARTS-III measurements made at LAX and Oakland Bay Area (OAK) TRACON facilities (14). When the pre-ARTS-III measurements were made at Oakland in August 1972 (OAK-1) and at Los Angeles in November 1972 (LAX-1), the TRACON's were located in the towers. When the post-ARTS-III studies were carried out in July 1974 (LAX-2) and November 1974 (OAK-2), the TRACON's were located in buildings separate from the towers. ARTS-III had been operational for about 5 months at the times of LAX-2 and OAK-2.

Thirteen controllers served as subjects in LAX-1 and 17 in OAK-1. Nine of the original 13 controllers (69 percent) at LAX and 11 of the original 17 (65 percent) at OAK served as subjects in the post-ARTS-III studies.

The expectation that the benefits of ARTS-III would be realized in reduced ATCS workload was not entirely fulfilled. Table XX shows a significant reduction in adrenal steroid excretion by ATCS's using ARTS-III, indicating a reduction in chronic stress attendant on the change to automation. However, catecholamine excretion was significantly increased to such an extent that total stress (C_s) was greater in the post-ARTS-III population than it was in the pre-ARTS-III group (Fig. 11). HR showed no significant pre-ARTS-III to post-ARTS-III change at either LAX or OAK.

Other Federal Aviation Administration (FAA) studies of the effects of ARTS-III on controller workload in the TRACON's at IAH and at Boston Logan Airport have

TABLE XX. Comparisons of Levels of Urinary Stress Metabolites at Los Angeles (LAX) and Oakland (OAK) TRACON's Before and After ARTS-III Installation

	st				e				ne			
Facility	Rest	Work	Δ	P	Rest	Work	Δ	P	Rest	Work	Δ	P
LAX-1	521.3	1152.5	631.2	.01	0.38	1.19	0.81	.01	2.07	4.26	2.19	.01
LAX-2	382.9	700.1	317.2	.01	0.76	1.95	1.19	.01	3.30	5.42	2.12	.01
Δ	138.4	452.4			0.38	0.76			1.23	1.16		
P	.05	.01			N.S.	.01			N.S.	N.S.		
OAK-1	485.1	899.2	414.0	.01	0.39	1.25	0.86	.01	1.59	2.58	0.99	.01
OAK-2	319.7	679.5	360.8	.01	0.76	2.26	1.50	.01	2.24	3.47	1.23	.01
Δ	166.4	220.6			0.37	1.00			0.64	0.89		
P	.01	.01			.01	.01			.05	.01		

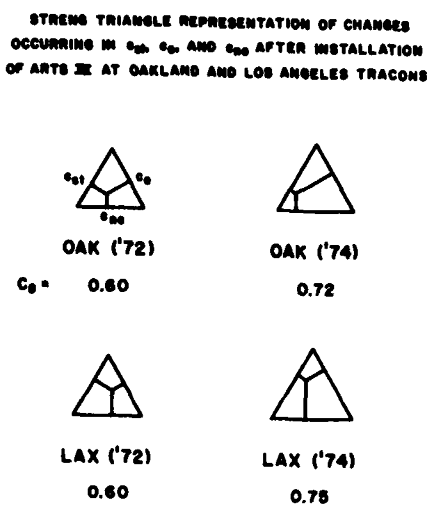

Figure 11. Streng triangles showing the increase in total stress in OAK-2 and LAX-2. See Fig. 1 legend for explanation.

shown a net reduction in ATCS's activities (14). Similarly, the objective measures of workload in our studies show either a net decrease in workload or insignificant change as a result of ARTS-III. Therefore, the increase in total physiological stress cannot be attributed to increased traffic.

Conversations with controllers and supervisors uniformly indicated that ARTS-III is a major improvement in ATC. No ATCS interviewed would have willingly returned to the old methods. However, there was also general agreement that 5 months of use is not long enough to develop total familiarity and trust in the equipment. Controllers at both LAX and OAK stated that a complete evaluation by controllers would be possible only after a good deal more experience had been gained in this new work environment.

Thus, the increase in the estimated total stress, entirely accounted for by increased catecholamine output, may be based on controllers' attitudes at that time toward ARTS-III. At the time of these studies, controllers' attitudes were somewhat ambivalent. Controllers liked the reduction in coordination both with other facilities and within the TRACON, they liked the sense of privacy at the radar islands, and they liked the decor and the illumination level. They did not like the location of the telephone panel and the inconvenience occasioned by unfamiliarity of other ATC facilities with new TRACON procedures.

The reduced level of excretion of st, after ARTS-III installation, indicates reduction in chronic stress. The chronic stressor could not be positively identified but it may have related to improved morale in the new quarters, enlarged controller responsibility (and thus less direct supervision), and improved labor-management relations.

D. Other Studies. The idea of "burnout" is deeply embedded in the lore of ATC. The term means that an ATCS believes that he is no longer able to perform his active ATC duties. The reasons are not readily discernible but are related to an accumulation of stress-related problems. Rose et al. have discussed this phenomenon and pointed out that controllers who showed burnout paradoxically demonstrated more psychological health at the start of their study than did those who did not show burnout. Furthermore, the physical health of burnouts did not show deterioration in parallel with burnout. Rose et al. concluded that burnout was related to an increased incidence of psychological problems, which they speculate could have resulted in later problems related to health and performance (21).

We conducted one study to evaluate relatively long-term changes in a group of ATCS's who had participated in earlier studies. Career progression, normal aging, and accumulated experience might cause long-term changes in stress levels (18).

ATCS's were identified as potential subjects through the FAA's Personnel Management Information System (PMIS). Their participation was solicited by mail; insulated mailing cartons for shipment of urine specimens were sent to those who volunteered to participate. They were all males and their ages ranged from 29 to 50 years. Thirty-two volunteers collected urine specimens as previously described, representing two successive rest and work periods. Subjects were instructed to refrigerate the specimens and airmail them to CAMI packed with ice. Specimens were cold when received at CAMI and were analyzed as described earlier; stress indices were calculated.

Eight of the ATCS's had been promoted or had transferred for other reasons to supervisory or other noncontroller jobs. Table XXI shows a comparison of changes in urine biochemistry of those 8 with changes for 24 other ATCS's who remained active in ATC positions. The data in the table may be summarized as follows: (i) Most members of both groups showed decreases in st excretion at rest and at work in the second study relative to the first study. (ii) Most members of the active controller group showed increases in e excretion at rest, while equal numbers of noncontroller subjects showed increases and decreases in e excretion at rest. (iii) In the second study most active controllers showed a decrease in e excretion at work. Most noncontroller subjects showed increases in e excretion at work. At rest, equal numbers of noncontrollers showed increases and decreases in ne excretion. At work, slightly more noncontrollers showed decreased ne excretion than showed increases. Most active controllers showed increases in ne excretion at rest and decreases at work.

Table XXII shows a comparison of individual indices and C_s for active controllers and noncontrollers and the changes from first to second studies. The st index, c_{st}, is significantly lower in the second study than it was in the first. For the noncontrollers, c_e is lower in the second study with marginal significance. C_s is lower in the second study for both groups because of the strong effect that c_{st} has on the average. The norepinephrine index, c_{ne}, showed no significant change for either group.

The data in Table XXII are shown on the Streng diagram in Fig. 12. It is apparent that total stress is reduced in noncontrollers to a greater degree than in active controllers.

Because of the small number of controllers represented in this study, conclusions are guarded if not tentative. With that in mind, it can be pointed out that both groups showed a decrease in st excretion level. This finding can be interpreted to mean that chronic stress is less in the second study than in the first. It should be mentioned again that only five first-study facilities are represented: ORD, IAH, and OPF ATCT's; LAX TRACON; and Miami (MIA) ARTCC. Because all of these original facilities had comparatively high stress levels, it is not unexpected that chronic stress of the group would be reduced when a move was made somewhere else, but the possibility also exists that with time the job becomes easier for some people--a counterburnout phenomenon.

An additional explanation may be based on improvement in the work situation. An earlier study showed that the introduction of ARTS-III was associated with a reduction in st excretion (14). There was an interval of 5 to 9 years from the first until the second study, a period during which many improvements were made in the ATC system.

These ATCS's were 5 to 9 years older at the time of the second study, which may also partly explain the decrease in st excretion. Reduction in st is known to accompany the normal process of aging (5,19,23).

During the 10-year period over which these ATCS stress studies were carried out, some of the participating ATCS's experienced various disabling medical conditions. Notations regarding these medical conditions requiring either waiver or retirement are in the controllers' files in the Aeromedical Certification

TABLE XXI. Number of Subjects and Directions of Change in Urine Biochemistry From the First Study to the Second Study

Type of Work, Second Study *	Total Number	17-KGS No. Showing Increase / Decrease		E No. Showing Increase / Decrease		NE No. Showing Increase / Decrease	
		REST	WORK	REST	WORK	REST	WORK
NONCONTROLLER	8	0(0)** / 8(60)	0(0) / 8(74)	4(55) / 4(29)	5(75) / 3(41)	4(23) / 4(28)	3(20) / 5(28)
ACTIVE CONTROLLER	24	2(86) / 22(38)	4(57) / 20(44)	19(115) / 5(9)	6(42) / 18(29)	18(43) / 6(29)	7(23) / 17(25)

* All subjects were active controllers in the first study.

** Numbers in parentheses are the mean percent increase/decrease for each hormone.

TABLE XXII. Stress Indices for Noncontrollers and Active Controllers: Comparison of First and Second Studies

Type of Work,	Stress Index--Mean Values			
Second Study	First Study	Second Study	Change	P <
ACTIVE CONTROLLER				
c_{st}	0.84	0.33	-0.51	0.001
c_e	0.53	0.68	+0.15	0.05
c_{ne}	0.70	0.69	-0.01	NS
C_s	0.69	0.57	-0.12	0.05
NONCONTROLLER				
c_{st}	0.78	0.19	-0.59	0.001
c_e	0.48	0.47	-0.01	NS
c_{ne}	0.73	0.54	-0.19	NS
C_s	0.66	0.40	-0.26	0.05

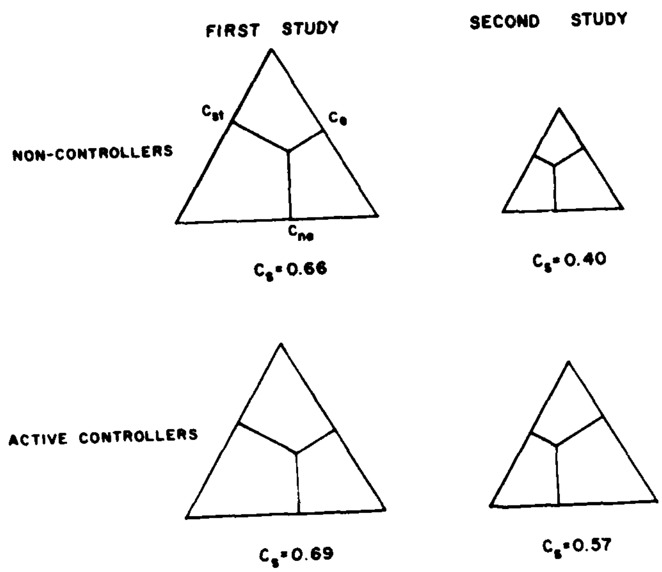

Figure 12. Diagrammatic representation of stress in noncontrollers and active controllers. Comparison of first and second studies.

Branch of CAMI. These files were searched and 36 controllers were identified who had developed pathology after the time of the stress study in which they served as subjects (16). These controllers showed pathology in one or more of three groups: gastrointestinal, neuropsychiatric, and cardiovascular (Table XXIII). A further breakdown of the three conditions by region and facility is shown in Table XXIV.

The individual and composite stress indices for normal controllers (those without a pathology file) and those with pathological conditions are shown in Table XXV. The table shows that for the whole population of controllers, those who developed gastrointestinal pathology had significantly ($p < .001$) higher c_{st} than did their normal counterparts at the time they were studied. The index for norepinephrine (c_{ne}) was also elevated significantly ($p < 0.05$) over the normals for the cardiovascular pathology group.

When the individual facilities were considered, c_{ne} was significantly ($p < 0.05$) elevated in the cardiovascular pathology group at MIA ARTCC (Table XXVI). Norepinephrine is the principal catecholamine liberated by the sympathetic nervous system and is, therefore, the main regulator of arteriolar resistance. Norepinephrine has also been shown to have pronounced effects in causing arrhythmias and fatty changes in the hearts of dogs (8). There are no other points of significant difference.

This study suggests that high levels of urinary adrenal steroids are related to the presence or later development of gastrointestinal disease, the most common "stress related" ailment. As shown in Table XXIII, the principal subcategories of that disease relate to ulceration of the stomach and duodenum. Ulcers have long been known to be related to high levels of endogenous steroids (3,6,26).

This study suggested that excretion levels of st and ne may be predictive of gastrointestinal ulceration, heart disease, and hypertension. However, because of the small number of controllers in each diagnostic category, the statistics leave much to be desired. These findings are, therefore, guarded.

The physiological response to real-life stressors, as determined by a battery of measurements, is difficult to interpret. Invariably, a mixture of stressors is involved, some related to the work situation, others to personal matters. The response is similarly mixed and not always clearly related to known stressors. Interpretations of the real-life stress response would be substantially improved if physiological and biochemical responses to "pure" stressors could be defined. The following experiment was carried out with the goal of providing such data (17).

Ten healthy paid men (not ATCS's) ranging in age from 19 to 26 years (average 21.9 years) served as subjects in the experiment. Each subject was challenged with two tasks; one was purely physical with no competitive element (treadmill), the other was a competitive task that required minimal physical activity ("Pong"). Order of presentation of the task was balanced. In each task, subjects were required to work in 50-min episodes. In the 10 min following each work episode, urine collections were made, rest was allowed, and water was imbibed to replace urinary loss. This schedule for each task was maintained for 3 h. The treadmill was set at 3 miles per hour with no grade.

TABLE XXIII. Distribution of Diagnoses Among Three Major Disease Categories

Disease Category	Diagnosis	Percentage Occurrence
Gastrointestinal		
	Gastric Ulcer	15.4
	Duodenal Ulcer	15.4
	Peptic Ulcer	15.4
	Gastritis	15.4
	Gall Bladder	7.7
	Other	30.7
Cardiovascular		
	Myocardial Infarction	26.7
	Coronary Insufficiency	6.7
	Hypertension	33.3
	Angina	13.3
	Arteriosclerotic Heart Disease	13.3
	Arrhythmia	6.7
Neuropsychiatric		
	Anxiety Reaction	21.8
	Anxiety Depression	21.8
	"Neuroses"	8.7
	Cluster Headaches	4.3
	Depression	4.3
	Personality Disorder	4.3
	Schizophrenia	8.7
	Anxiety Neuroses	21.8
	Psychosomatic Illness	4.3

TABLE XXIV. Distribution of the Three Major Disease Categories Among Regions and Facilities

Region	Facility	Gastro-intestinal	Cardio-vascular	Neuro-psychiatric
Southern				
	Opa Locka Tower	0	0	1
	Miami ARTCC	3	8	12
	Atlanta ARTCC	0	1	3
		3	9	16
Southwest				
	Houston Inter-continental Tower	1	1	0
	Fort Worth ARTCC	1	1	3
		2	2	3
Central				
	O'Hare Tower (1968)	4	1	2
Western				
	Los Angeles TRACON	0	0	0
	Oakland TRACON	1	0	0
		1	0	0

TABLE XXV. Pathology and Grouped Stress Indices for the Entire Subject Population

	c_{st}	P*	c_e	P*	c_{ne}	P*
Normal	0.67	≤ 0.01	0.60		0.77	
Gastrointestinal	1.12	0.01	0.61	NS**	0.68	NS
Cardiovascular	0.94	NS	0.74	NS	1.25	≤ 0.05
Neuropsychiatric	0.64	NS	0.82	NS	0.85	NS

*P = Level of significance of difference between normal and pathological conditions

**NS = Not significant

Unpaired t-test

TABLE XXVI. Pathology and Individual Stress Indices for Various ATC Facilities

Facility	Category	c_{st}	$\underline{p}$*	c_e	$\underline{p}$*	c_{ne}	$\underline{p}$*
Houston Intercontinental Tower							
	Normal	1.01		0.40		0.59	
	Gastrointestinal	1.77	†	0.96	†	0.57	†
	Cardiovascular	1.77	†	0.96	†	0.57	†
	Neuropsychiatric	0.00	†	0.00	†	0.00	†
Oakland TRACON							
	Normal	0.37		0.85		0.48	
	Gastrointestinal	0.48	†	0.41	†	0.30	†
	Cardiovascular	0.00	†	0.00	†	0.00	†
	Neuropsychiatric	0.00	†	0.00	†	0.00	†
Los Angeles TRACON							
	Normal	0.63		0.38		0.79	
	Gastrointestinal	0.00	†	0.00	†	0.00	†
	Cardiovascular	0.00	†	0.00	†	0.00	†
	Neuropsychiatric	0.00	†	0.00	†	0.00	†

*$\underline{p}$ = Level of significance of difference between normals and diseased

**NS = Not significant

† = Number of cases insufficient for statistical treatment

"Pong" is an electronic television game based on ping-pong. A "ball" is automatically and randomly directed to one side of the TV screen. Each of the two players with a knob on the game console controls a "bat" on one side of the display. The players attempt to intercept the ball with the bat, thus returning the ball to the opponent. When a player misses the ball, a point is automatically scored for the opponent. The cumulative score of each player is displayed after each point. The first player to score 15 points wins the game. One of the researchers acted as opponent for all the subjects; she was an expert at the game and was rarely defeated.

On arrival at the laboratory, subjects were requested to void urine and discard it. They then had electrocardiographic electrodes attached to their chests, were given 250 mL of water to drink, and were asked to rest in the supine position on a cot for 50 min. At the end of the rest period, subjects collected a urine specimen and began the first work episode.

The electrocardiogram was recorded on an Avionics Electrocardiocorder for continuous registration of HR. Urine specimens were collected in a 500-mL graduate cylinder, the volume was recorded, and aliquots were taken for analysis of st, e, and ne. Aliquots were kept frozen until analyzed. Urinary stress hormone values were expressed as total weights of the substances excreted during each 50-min episode.

The results of urine and HR analyses are shown in Tables XXVII and XXVIII. There are no statistically significant differences in excretion levels of urinary metabolites for corresponding episodes of the two tasks. HR's are significantly higher for the treadmill than for the Pong task (Table XXVII). Rest-to-work differences show that the increment in e excretion is significantly greater during the Pong task than during the treadmill task. Rest-to-work differences in excretion of 17-KGS and ne are not significant for either task. The rest-to-work increase in HR is significant for the treadmill but not for the Pong task (Table XXVIII).

As reported in an earlier section, field experiments have shown that the amount of e excreted is significantly and directly related to traffic count and to radio transmission time. Field study data have strongly suggested that adrenal steroid excretion is related to chronic stressors such as labor-management difficulties and that ne excretion is related to physical activity. This laboratory experiment strengthens the interpretation that e excretion is related to mental tasks such as ATC and not to physical tasks and, therefore, is the best single indicator or response to ATC work per se.

E. Conclusion. It should not be inferred from these within-group studies that excessive or unusual levels of stress were present in the ATC work force. Studies of non-ATC populations in which exactly comparable measurements were made are almost nonexistent. However, Hale et al. compared O'Hare ATCS's (the ATCS's who showed the greatest stress) with various groups previously studied at the U.S. Air Force School of Aerospace Medicine. They found that ORD ATCS's did not uniformly show greater stress levels than did Air Force aircrews, men undergoing altitude chamber tests, or laboratory scientists off duty at home (4). Smith et al., using an anxiety inventory, showed that psychological measures remained relatively uniform across facilities and suggested that air traffic work, no matter what the nature of the facility, had no dramatic impact on the psychological states of controllers. Thus, it is clearly inappropriate from the psychological perspective to describe ATC work, as is commonly done in the popular press*, as an unusually stressful occupation. Popularized accounts of controller stress deal with the exceptional rather than the typical controller or facility. Further, such accounts tend to assume that physiological and psychological changes associated with simple workload effects are undesirable and invariably have long-term negative consequences. That assumption is highly questionable, particularly in view of the expressed preference of ATCS's for heavy as opposed to light workloads (24).

* See Ref. 15 for references to three such popular press articles.

TABLE XXVII. Comparison of Excretion Values and Heart Rates for Pong and Treadmill Tasks*

Task	Total Amounts of Hormones Excreted 17-KGS mg	E ng	NE ng	Heart Rate (Beats Per Minute)
Rest (Pong)	0.70	1,237	3,603	64
Rest (T-Mill)	0.67	1,214	4,274	64
P	NS**	NS	NS	NS
Pong 1	0.70	1,619	3,809	73
T-Mill 1	0.59	1,741	4,384	101
P	NS	NS	NS	0.05
Pong 2	0.62	1,720	3,379	73
T-Mill 2	0.67	1,463	3,813	100
P	NS	NS	NS	0.05
Pong 3	0.59	1,750	3,833	70
T-Mill 3	0.58	1,491	3,581	98
P	NS	NS	NS	0.01

* Group Averages
** T-test

TABLE XXVIII. Statistical Significance of Rest-To-Work Differences for the Various Measurements*

	Level of Significance of Difference Between Rest and Task (P**)			
TASK	17-KGS	E	NE	HEART RATE
Pong 1	NS	0.01	NS	NS
Pong 2	NS	0.01	NS	NS
Pong 3	NS	0.05	NS	NS
T-Mill 1	NS	NS	NS	0.01
T-Mill 2	NS	NS	NS	0.01
T-Mill 3	NS	NS	NS	0.01

* See Table XXVIII for actual values

** Paired t-test

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